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Cultures of Engagement and Innovation: Realizing Purdue's Public Mission of Access and Impact in Engineering Education

ROBIN S. ADAMS

ANDREW O. BRIGHTMAN

JENNIFER DEBOER

LEAH H. JAMIESON

WILLIAM C. OAKES

DONNA M. RILEY

PAIGE RUDIN
Purdue University
West Lafayette, IN

ABSTRACT

Purdue University's commitments as a public land grant institution that purposefully integrates education, research, and service has enabled the university to develop as a site of innovation and impact at scale, making strategic investments and taking bold risks that produce benefits within wider social, political, and economic systems. We present a description of Purdue's culture and processes reflecting a research-practice innovation cycle, illustrated by examples spanning seven decades in the engineering education space where practice is a generative site for emergence of new ideas, and research in turn informs practice. Innovation as part of a research-practice cycle is not undertaken for its own sake, but with meaning and purpose. It keeps in view how to enable infrastructure, how to scale, adapt, and personalize, and how to make education inclusive and global. Innovation at scale requires relationship building and working within institutional cultures, building towards transformation and impact using what is available, with a knowledge of how it can travel on to other destinations.

Key words: Innovation; Institutional culture; Research to practice

INTRODUCTION

In the mid-to-late nineteenth century, the United States government made a series of investments in higher education that launched a global model for universities. Land grant institutions were

founded on principles of access for a broad portion of the population, across lines of race, gender, and class. With a focus on preparation in technical and agricultural fields, their mission extended to offering a comprehensive array of subjects "in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life" (7 US Code §321 1862). This mission of access was accompanied by a commitment to conduct research of benefit to the public, and to deliver the benefits of knowledge generated to communities through extension services.

Purdue University's motto, "Education, Research, Service" reflects this trifold land grant mission. It is through these commitments to the public and the purposeful integration of education, research, and service that our institution has been able to develop as a site of innovation and impact at scale, making strategic investments that produce benefits within wider social, political, and economic systems. We present below a description of Purdue's culture and processes reflecting a research-practice innovation cycle, followed by multiple examples in the engineering education space. In this virtuous cycle, practice is a generative site for emergence of new ideas in research, and research in turn informs practice (Jamieson and Lohman 2012). Generating new knowledge focuses not only on what works but also asks questions that challenge the status quo of how we think, and the purposes and aims we assign to education of students. For research to inform practice and be truly transformative and impactful, it must be translational, building relationships for practical use, balancing our understandings of engineering as a science (objective) and as a professional practice (contextual and subjective).

Innovation as part of a practice-research cycle is not undertaken for its own sake, but with meaning and purpose. It keeps in view how to enable infrastructure, how to scale, adapt, and personalize, and how to make education inclusive and global. Innovation at scale requires relationship building and working within institutional cultures, building towards transformation and impact using what is available, with a knowledge of how it can travel on to other destinations. The six examples below illustrate how Purdue's land grant commitment to the public good, integration across education, research, and service, and a willingness to take risks and make bold moves in uncharted spaces have fueled a cycle of practice-research innovation for over 65 years.

FIRST-YEAR ENGINEERING

Purdue was early in committing to the idea of a common first year for engineering students, instilling an identity as an engineer through an introduction to the profession as a whole, prior to specialization in a subdiscipline. From the early 1950s through the late 1960s, Purdue's Engineering Dean, George Hawkins, was involved in writing two national reports on engineering education,

the Grinter Report (1955) and the Goals Report (Walker, Pettit & Hawkins 1968). Both recognized a need in the Post-War Era to strengthen engineering's science foundations and to be responsive to societal needs, drawing on liberal education courses rounding out the engineering curriculum. Purdue's own curricular innovations became a national model emulated by many (Radcliffe 2016).

In 1954, Purdue announced the creation of the first-ever Department of Freshman [sic] Engineering with the mission of preparing and advising first-year students in engineering. By the 1960s, Purdue was drawing on cutting edge research on campus to improve the experiences of engineering students, from early flipped-classroom techniques using audio tutorials to systematic approaches to advising and retention, Purdue was activating practice-research innovation cycles (LeBold 1990, Radcliffe 2016). In the 1970s and 1980s, Purdue's Center for Instructional Development in Engineering (CIDE) focused on faculty development, curriculum design, and approaches to teaching engineering (Wankat and Oreovicz 1993).

More recently, research has grown to consider, among other things, diversity and inclusion, engineering identity development, the high-school to college transition and life-long learning, problem-based learning approaches, the design of learning spaces, critical review of the nature of engineering, teaming, methodologies for engineering education research, peer feedback, access and equity, and education in engineering at scale (e.g., Morelock 2017; Borrego, Karlin, McNair, & Beddoes 2013; Stevens, Johri, & O'Connor 2013; Case & Light 2013; Brophy, Klein, Portsmore, & Rogers 2013; Callahan, Farrell, & Minerick 2018). Findings are developed from practice in the First-Year Engineering Program at Purdue and are used to further improve the student experience. In 2007, the First-Year Engineering Program moved into new spaces specifically designed for team-based and active learning. A new year-long first-year engineering sequence was introduced that capitalized on the space and set the pace for active learning at scale in engineering with 120-student sections (up to 18 sections per semester). Course coordination is led by faculty curators and managed by a team of instructional support staff. Each class of 120 students is facilitated by a team of six, including an instructor of record (usually tenure-track faculty or other permanent instructor), a graduate teaching assistant, and four undergraduate peer teachers. The rollout of this model resulted in a significant and immediate increase in first-year retention within engineering.

DIVERSITY, INCLUSION, ACCESS, AND EQUITY

Honoring its land grant vision of an education that is accessible by all, Purdue faculty and students have combined various education, research, and service initiatives over time to achieve innovative approaches to promoting diversity and inclusion in and out of the classroom. In 1969, the first Women

in Engineering Program (WIEP) was established as a woman-led campus tour guide program to promote enrollment by other female engineering students, in response to a directive from Freshman Engineering Head Clifford Gerde to (paraphrased) "make things better for the women students and increase the number" (Donna [Frohreich] McKenzie, personal communication, March 23, 2019).

The first chapter of the National Society of Black Engineers (NSBE) was founded by Purdue students, staff and faculty in 1975, building on Black student campus activism in the preceding decade. The Minority Engineering and Women in Engineering Programs were part of the Department of Freshman Engineering for many years, supporting first-year students as well as outreach for middle and high school students. This integration created a synergy in the research-practice cycle that was evident in early publications (LeBold & Salvo 1964, LeBold 1976). Sustained leadership in research investigating the influence of race and ethnicity, class, and gender in the student experience led by the School of Engineering Education further supports efforts to understand and facilitate learning for all types of students.

INTERDISCIPLINARY AND MULTIDISCIPLINARY ENGINEERING

To accommodate the interests of a growing group of students who desired to study engineering beyond the bounds of a single discipline of practice, Purdue's Interdisciplinary Engineering (IDE) program emerged in 1969 as a radically student-centered curriculum option to engage dynamic thinkers. The program serves as a crucible for creating curricular tracks that require connecting across multiple disciplines at an advanced level to address societal challenges. While maintaining a well-established set of student-designed degree concentrations such as acoustical engineering and engineering management, the program also laid the foundation for establishing new programs, divisions, and schools such as the Weldon School of Biomedical Engineering, Division of Environmental and Ecological Engineering, and School of Nuclear Engineering. After IDE became part of the School of Engineering Education in 2004, the institution added an ABET-accredited degree path (requiring a new distinct name, Multidisciplinary Engineering (MDE)). More recent degree concentrations pursued by MDE student cohorts include humanitarian engineering, visual design engineering, and the first-of-its-kind concentration in theatre engineering. Students can also self-design a plan of study such as diversity and inclusion engineering and veterinary health engineering. The ability to establish well-developed and commonly-pursued tracks enables specific interests to achieve scale. Just as our first-in-kind tracks expand our imaginations around what engineering can be, the humanitarian engineering concentration expands the land grant mission by pushing the bounds of what outreach and extension can mean.

Across all plans of study, curricula are unified by core technical competencies in basic engineering skills and overlaid with proficiency in formulating and addressing complex problems as a future engineering professional. Beyond a discrete series of required classes, students have agency and flexibility to pursue other coursework and learning experiences, enabling the academic-practice transition by emphasizing the development of foundational professional skills. Students participate in a final capstone design experience demonstrating the convergence of design thinking, interdisciplinary thinking, and the integration of auxiliary capabilities developed in each individualized curriculum (Adams and Turns, 2020).

An emphasis on reflective practice is woven throughout the curriculum to engage students in building identities without the normalizing and defined structure of traditional disciplinary programs. Students are empowered to design personalized pathways, often taking bold risks to study novel combinations of topics without the understanding or validation of established structures. So-called "Purple Squirrels," a community-building departmental nickname, find their homes in the "Nest" while training as future leaders who can solve problems using their unique strengths and abilities developed across disciplines.

EPICS – ENGINEERING PROJECTS IN COMMUNITY SERVICE

The 1990s brought growing criticism from industry that engineering programs were producing graduates with strong technical backgrounds but few of the professional skills desired by industry (Dahir 1993, ASEE 1994). Purdue's EPICS program was launched in 1995 as a vertical track of courses in which undergraduates earned academic credit for team-based design projects that delivered technology-based solutions to problems identified by not-for-profit organizations in the community (Coyle, Jamieson & Dietz 1996; Coyle, Jamieson & Oakes 2006). In a break with traditional academic structures, EPICS courses encouraged multi-semester/multi-year participation. Teams were vertically integrated, soon including first-year students through seniors, and multidisciplinary across engineering fields and ultimately across the university. The program design provided the time and context to enable students to develop technical depth and multi-disciplinary breadth; experience start-to-finish design; and develop and hone professional skills and qualities including communication, customer awareness, teamwork, leadership, project management, and creativity.

At the same time that students were increasingly being called on to develop these skills, many community organizations were looking for ways to take advantage of technologies that could significantly improve the services they provided, but which often came at a cost that was beyond their reach. By forming long-term partnerships between student teams and community partners,

EPICS created a sustainable framework for addressing these mutual needs. It has become a tangible expression of Purdue's land grant mission and, although it grew out of practice, has spawned research in topics including ethics, entrepreneurship, multidisciplinary teaming, human-centered design, and community partnerships. It has also become a facet of Purdue Engineering's recruiting and retention of under-represented students, with women participating at higher rates than the overall college (Matusovich, Oakes & Zoltowski 2013) and comprising approximately half of the participants in the EPICS learning community for first-year students (Oakes, Hsu & Zoltowski 2015). Reflecting the theme of scale, EPICS has grown in size and reach, with more than 1,200 students engaged annually on 135 ongoing projects at Purdue. As the definition of "community" has broadened, EPICS, which initially focused on local projects, has expanded to include a portfolio with 25% global projects, including integrating EWB-USA (Oakes, Zoltowski, Schmotzer & Valenca 2015). In 1999 EPICS launched a university consortium to support the adoption of EPICS by other institutions (Oakes, Zoltowski & Huff 2014). There are currently 53 institutions globally that are part of the EPICS University Consortium and a global partnership with IEEE (Kam 2015). The IEEE partnership also extends EPICS into a program to introduce middle and high school students to engineering through addressing needs within their local community. This effort has seen significant impact on diversity and increasing students' interest in engineering.

PH.D. IN ENGINEERING EDUCATION

By the early 2000s, faculty in the Department of Freshman Engineering had persisted in asking research questions that grew out of their experiences with first-year students. They began to consider creating a Ph.D. program that would formalize and grow these activities in research to improve education. There was a particular interest in formalizing research related to the whole pre-college experience, moving from an outreach model to a more systematic approach rooted in the scholarship of discovery and engagement (Haghighi 2005). Recognizing the synergistic potential of tying together educational research and the innovative Freshman Engineering and IDE bachelor's programs, the Trustees approved the merger of the Department of Freshman Engineering with the Division of Interdisciplinary Engineering, forming a Department of Engineering Education that would also be the administrative home of the Ph.D. program in Engineering Education (Radcliffe 2016). This was a bold first that also wove together education, research, and service to further Purdue's public mission.

Founding faculty of the Ph.D. program understood the transition that traditionally-educated engineers need to undertake to move into research that involves and engages people (the ultimate human-centered design scenario). In designing the Ph.D. program, these educators reviewed other

interdisciplinary graduate programs in engineering, science education, the learning sciences and elsewhere, building curriculum upon a coherent framework, not just "best practices" or "greatest hits," and emphasizing critical dialogue and meaningful research-to-practice action. This foundational core was groundbreaking in its time and continues to stand out for its depth, breadth, and cohesion (Adams, Pawley & Jesiek 2012; Banks et al. 2004).

ENE's Ph.D. program engages diverse future leaders in engineering education from around the world and empowers them in a global community capacity building effort. The Ph.D. program recruits students from around the world, many of whom are already instructors or who have aspirations to teach engineering or be in engineering leadership positions in their home countries. These future leaders learn scholarly approaches to studying, teaching, and learning engineering, and then take these tools back to universities in Colombia, Ghana, India, Mexico, Turkey, and elsewhere around the world. Their universities often have a broad access mission and prepare large and growing numbers of young people explicitly for key local development goals. Thus, there is a clear connection forged between the Morrill Land Grant Act's vision to serve the community and the mission and vision of many of the institutions where our graduates serve.

The creation of the Ph.D. program greatly accelerated and expanded engineering education research at Purdue. As researchers committed to generating new knowledge, Purdue Engineering Education faculty have, over the past fifteen years, developed an impressive set of educational innovations including theoretical frameworks, research methodologies and methods, research tools including databases and instruments for measuring any number of developing student capacities, engineering-specific instructional approaches, and software products that support classroom activities such as team management (e.g., Streveler & Smith 2006; Crismond & Adams 2012; Madhavan et al. 2014; Moore et al. 2014; Ohland et al. 2014; Slaton & Pawley 2018). As the program grew to two dozen faculty, it became possible to move from individual, isolated work to larger collaborative projects across Purdue and beyond Purdue, leveraging research power and partnerships for large-scale change. We live the research-to-practice cycle as part of our "normal work." One embodies the other.

PRACTICE TO RESEARCH TO PRACTICE

Traditional Disciplines Transforming - Another example of the research and practice cycle that circumscribes a unique contribution to engineering training can be seen in the Mechanical Engineering Education Research Center at Purdue (MEERCatPurdue). The center was formed by faculty from engineering education and mechanical engineering, combining extensive experience with engineering education scholarship and innovations in mechanical engineering teaching and learning.

The mission of the center is "...to enable the holistic formation of Mechanical Engineers by bridging research & practice." This is done through deep and thoughtful engagement with a large quantitative and qualitative dataset on students' and instructors' experiences in Mechanical Engineering (ME), a broad study of department culture and cultural factors that allow for educational innovation, and practice-oriented strategies that can be implemented throughout students' educational careers and into their work life. As research findings point towards recommendations for practice, they are implemented, and the ME classroom as a testbed then inspires new, important research questions.

Global Innovation - Purdue engineering engages with the most pressing problems around the world. This includes engineering solutions to alleviate poverty. Purdue engineering founded what is now the Shah Family Global Innovation Lab to catalyze engineering responses to the myriad challenges that accompany poverty, including engineering solutions to health, conflict and political instability, resource delivery, education, and water and sanitation. More recently, Purdue led the creation of a consortium to match engineering scholars with community stakeholders around the world to broaden both research and extension/translation of research to impact (Wyles 2018). Faculty in engineering education specifically work to train their peers who are engineering teachers around the world and co-conduct research with young, new teachers and scholars in Colombia, Ethiopia, India, and China.

Engineering Ethics Education - With awareness of the prevalent ethical failures in engineering practice in many industries, both nationally and globally, faculty members in engineering education at Purdue recognized the essential need to develop more effective strategies for ethics education and thus to increase the scholarly research on pedagogy, assessment, and the factors influencing ethical engineering cultures. Purdue researchers have developed pedagogy and assessment tools for ethics education, research on better understanding ethical reasoning, ethical team cultures, ethics educator mindsets, social responsibility, global aspects of engineering ethics, and industry cultures and understandings of ethics. These research-driven findings have led to innovations in the practice of ethics education. However, new efforts toward more integrated ethics education on a national, and international, scale are still sorely needed. The engineering class of 2021 has just graduated and yet there is still deep concern that these new engineering students are not fully prepared to meet the high stress demands of the industries and the world that they will enter after four years, especially if they are called upon to provide ethical leadership and shape ethical cultures.

Continuing to develop innovative engineering education curricula that extend beyond ethical engineering to a whole new way of being an engineer in the world will be required if engineers are to participate responsibly in the mission to shape a sustainable global culture of human thriving. Educational innovations in engineering ethics also need to be translated into practice in industries that are important to the land grant mission in Indiana and the nation. Indeed, the types of educational innovations that have been driven by a decade of intense ethics research at Purdue will be furthered

by engagement much like the successful extension partnerships in the agricultural sector. Efforts such as these are underway, in collaboration with partners around the world, to advance the influence of state-of-the art ethics education and infuse both industrial and governmental sectors with engineers skilled and prepared to meet the demands of ethical leadership and cultural engagement for shaping a future of global well-being (Kim, Jesiek, Zoltowski, Loui, & Brightman, 2020).

CONCLUSION

Across Engineering Education at Purdue, research, teaching and learning, co-curricular and extra-curricular programs, and extension efforts have realized the vision of a land grant university. Now, over 150 years later, scholars are re-examining the land grant act and re-imagining what the next phase of the act could be (e.g., Main, Smith, Fentiman, & Watson 2019). The six examples presented above demonstrate Purdue's unique realization and renewal of the land grant for the future – a broadened conception of the mission in three important dimensions. First, a broadening of the notion of engineering to include what the act variously called "the several pursuits and professions in life" and "scientific and classical studies." This innovation supports Purdue graduates in innovative, forward-thinking, and trailblazing new disciplines and practices of engineering. Second, this includes broad and thoughtful engagement with the global engineering education community. Through programs like EPICS and the variety of engineering disciplines represented by MDE, engineering education at Purdue has broadened the scope of the local community to be one outside the walls of the university, even so far as humanitarian need would take engineers around the world. The global becomes the new "local" community. Finally, we broaden the conception of who is an engineer, as exemplified in Purdue's engagement with the Women in Engineering Program, Minority Engineering Program, and the National Organization of Gay and Lesbian Scientists and Technical Professionals, and with engineering students and leaders from around the world.

Faculty in engineering education are pushing the boundaries of work with future engineers in the most marginalized communities. For example, Purdue researchers are working closely with students who are homeless/unaccompanied youth or who live in refugee camps. These students are often dismissed as potential architects of the engineering solutions their communities need; however, Purdue researchers thread all of the land grant notions described above together to expand engineering education to realize these students' potential. Research, teaching and learning, and outreach combine in this "scholarship of engagement" that is prototypical of the land grant mission. This clearly realizes the teaching mission of the land grant, supporting relevant engineering learning where it is immediately used. This outreach empowers students in their own locales to learn engineering, drive the needfinding

and product creation to solve their own problems, and to build on the tradition of agricultural extension in tapping into their own knowledge to transform their communities. And Purdue faculty collaborate with refugee students and unaccompanied youth learners to generate scholarship on how learning in this space can work, be innovative, and inform even more "traditional" formal engineering settings. Instead of adhering to the limited, restrictive existing channels for engineers to be trained, this work enables an unbounding of potential. This approach and the others innovated at Purdue challenge engineering education to broaden our conception of pathways into, through, and out of engineering formal education, re-affirming and prioritizing the land grant mission, and pointing to the future.

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AUTHORS

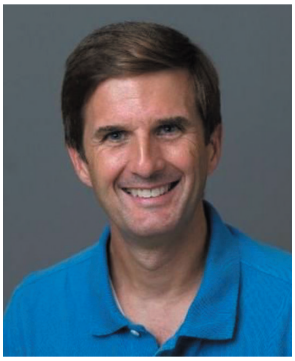
Robin S. Adams is Professor of Engineering Education at Purdue University and a national leader in researching interdisciplinary thinking and design learning, in connecting research and practice, and in building research capacity in engineering education.

She is the recipient of a 2008 NSF Career Award, a Design Studies best paper award (2003), and the Journal of Engineering Education's Wickenden Award for best paper (2007), She received degrees in education (Ph.D.), materials science and engineering (M.S.), and mechanical engineering (B.S.). rsadans@purdue.edu

Andrew O. Brightman, Ph.D., is Professor of Engineering Practice in the Weldon School of Biomedical Engineering. His research background is in cellular biochemistry, tissue engineering, and engineering ethics education. He is committed to developing effective pedagogies for ethical reasoning and engineering design and for increasing the diversity and inclusion of engineering education. aob@purdue.edu

Jennifer DeBoer is Associate Professor in the School of Engineering Education. Her research focuses on international education systems, individual and social development, technology use and STEM learning, and educational environments for diverse learners. Dr. DeBoer obtained her Ph.D. in international education policy studies from Vanderbilt University in 2012 and two bachelor's degrees in mechanical engineering and foreign languages from MIT. DeBoer currently serves as co-director of the International Institute for the Development of Engineering Academics (IIDEA) and associate editor for the IEEE Transactions on Education. deboerj@purdue.edu

Leah H. Jamieson is Ransburg Distinguished Professor of Electrical and Computer Engineering at Purdue University, John A. Edwardson Dean Emerita of the College of Engineering, and holds a courtesy appointment in Purdue's School of Engineering Education. She is a past president and CEO of IEEE. Jamieson is co-founder and past director of the Engineering Projects in Community Service (EPICS) program, for which she was a co-recipient of NAE's Gordon Prize for Innovation in Engineering and Technology Education. She was an inaugural recipient of the NSF's Director's Award for Distinguished Teaching Scholars and has been recognized with the IEEE Education Society's Harriet B. Rigas Outstanding Woman Engineering Educator Award and the Anita Borg Institute's Women of Vision Award for Social Impact. Jamieson holds a B.S. mathematics from MIT, Ph.D. in electrical engineering and computer science from Princeton, and honorary doctorates from Drexel and NJIT. She is a member of the National Academy of Engineering and the American Academy of Arts and Sciences and Fellow of IEEE and ASEE. LHJ@purdue.edu



William C. Oakes is a 150th Anniversary Professor, Director of the EPICS Program, Professor of Engineering Education at Purdue University and a registered professional engineer in the U.S.. He is one of the founding faculty members in the School of Engineering Education having had courtesy appointments in Mechanical, Environmental and Ecological Engineering and Curriculum and Instruction in the College of Education. He was the first engineer to receive the U.S. Campus Compact Thomas Ehrlich Faculty Award for Service-Learning. He was

a co-recipient of the U.S. National Academy of Engineering's Bernard Gordon Prize for Innovation in Engineering and Technology Education and the recipient of the U.S. National Society of Professional Engineers' Educational Excellence Award. He is a fellow of the American Society for Engineering Education and the National Society of Professional Engineers. oakes@purdue.edu

Donna Riley is Kamyar Haghighi Head and Professor in the School of Engineering Education at Purdue University. From 2013–2015 she served as Program Director for Engineering Education at the National Science Foundation (NSF). Riley spent thirteen years as a founding faculty member of the Picker Engineering Program at Smith College, the first engineering program at a U.S. women's college. Riley is the author of two books, *Engineering and Social Justice* and *Engineering Thermodynamics and 21st Century Energy Problems,* both published by Morgan and Claypool. She holds a B.S.E. in Chemical Engineering from Princeton University and a Ph.D. in Engineering & Public Policy from Carnegie Mellon University. She is a Fellow of ASEE. riley@purdue.edu

Paige Rudin is a recent graduate of Purdue University's Multidisciplinary Engineering program. She self-designed a concentration in Veterinary Health Engineering, combining engineering classes and pre-veterinary study to further understanding of animal health's role in global health systems. Currently, she works as a Truman-Albright Fellow in Washington, D.C. and intends to return to Purdue for veterinary school. rudin@purdue.edu